Libera

Understanding Earth's Energy Budget

LASP • JPL • LBL • UA • CSU • UM • NIST • NOAA • Ball • SDL

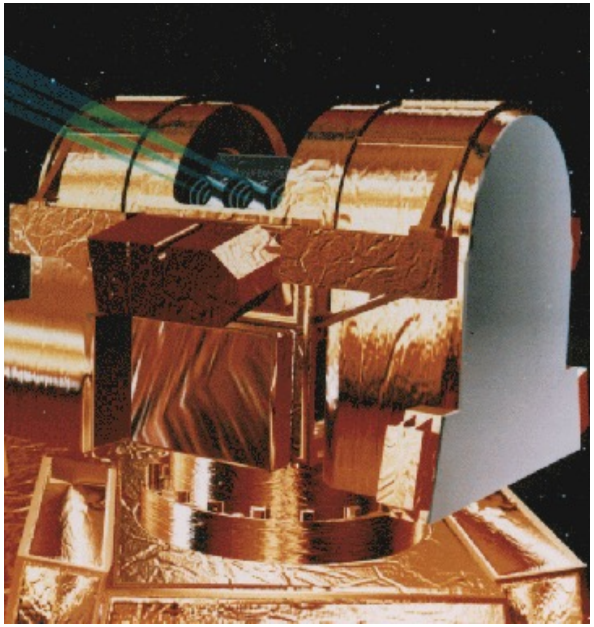
The Libera Instrument and Calibration and Characterization Concepts

Dave Harber & Libera Team

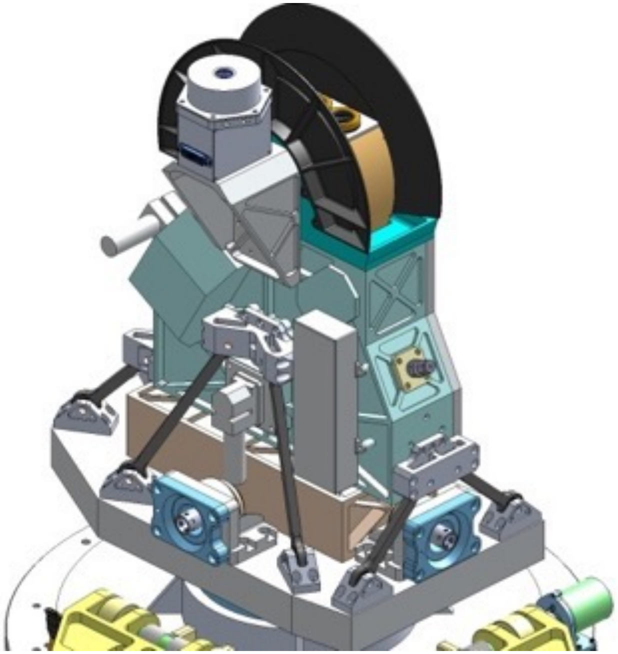
CERES and Libera

In order to maintain seamless data continuity Libera shares many key design features with CERES

CERES



Libera



Justification for CERES Similarities

Must share key instrument characteristics

in order to extend the CERES data record

Similarities

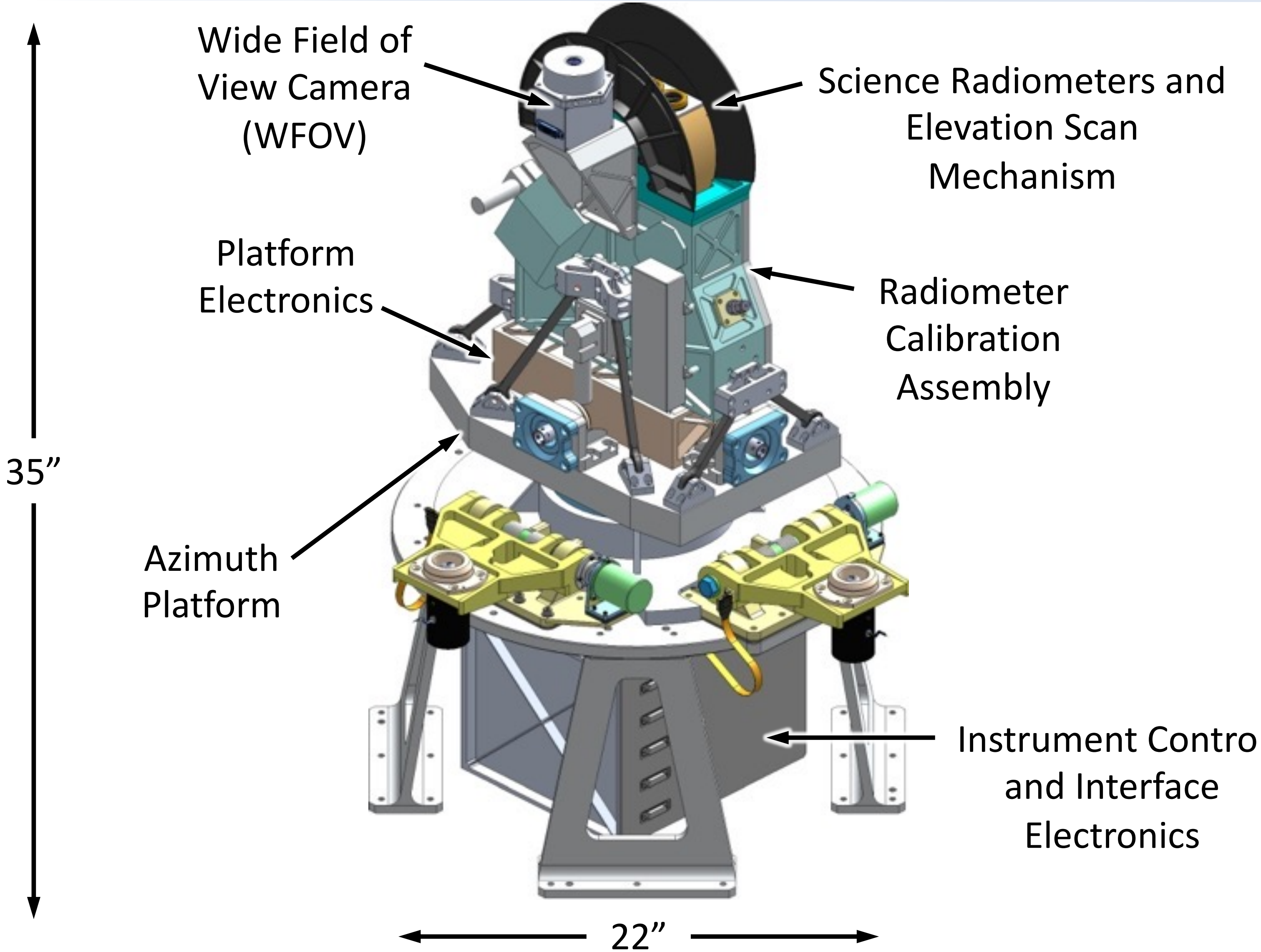
- Cross-track scanning
- Optical design
- Point-spread function
- Channels and spectral-response functions
  - Short Wave Channel (SW)
  - Long Wave Channel (LW)
  - Total Channel

Justification for Differences

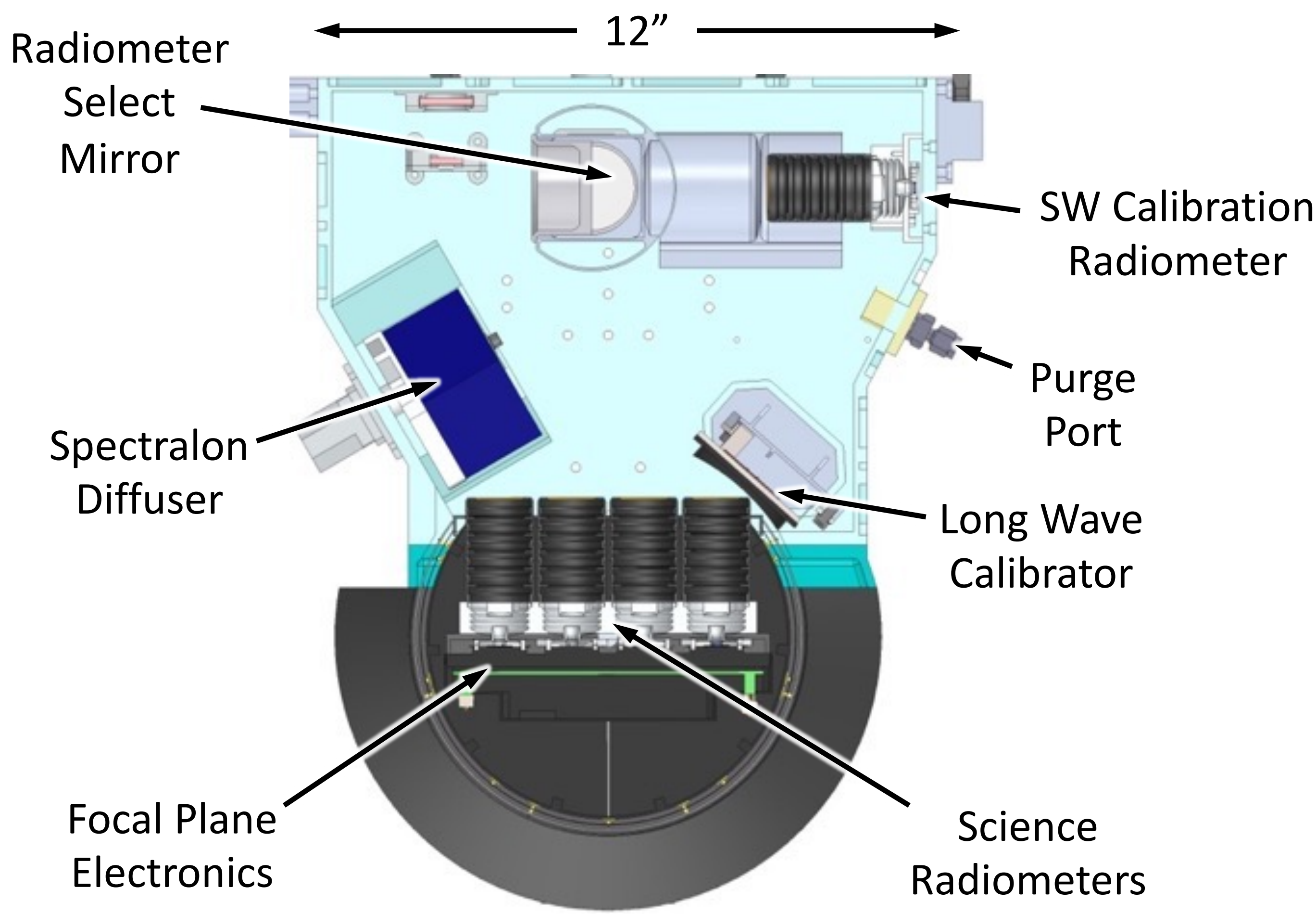
In order to improve accuracy, stability, and capability

- New type of detector
  - New technology permits higher accuracy and improved stability and easier manufacturability
- New internal calibration sources
  - Add spectral tracking of SW channel, improve long-term stability
- Additional channel
  - Split Shortwave Channel (SSW)
  - Provide insight into SW scattering and absorbing processes
- Wide FOV Camera
  - Test independent scene identification, ADM generation, work towards self-contained observation system

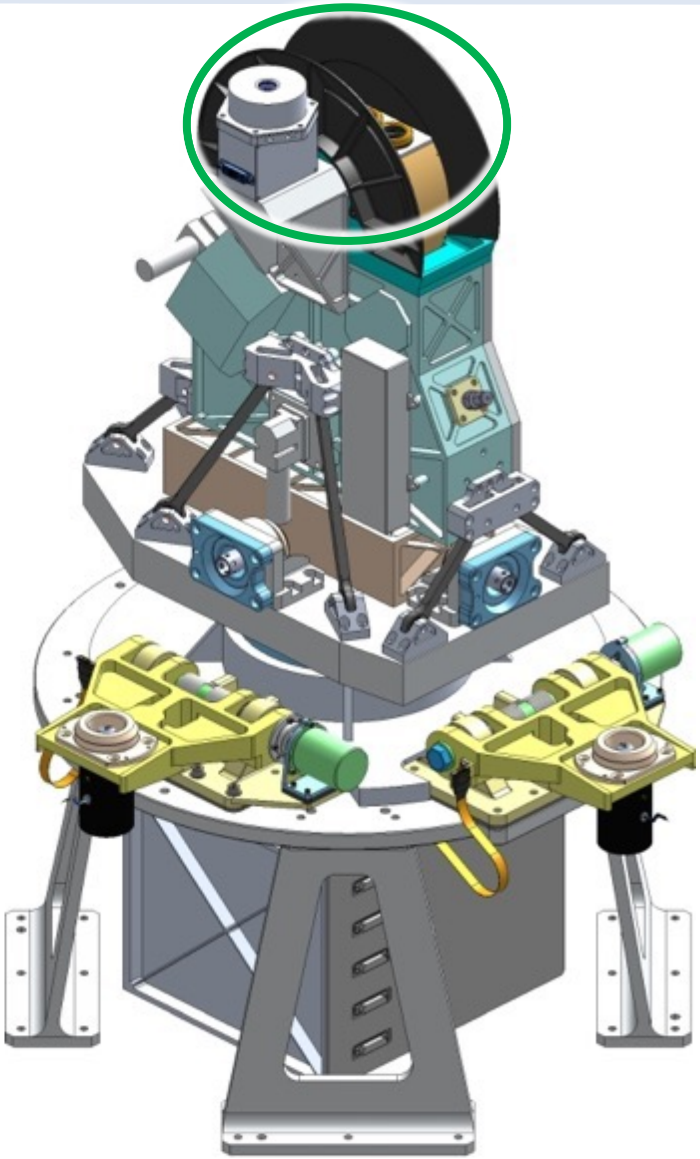
High-Level Overview

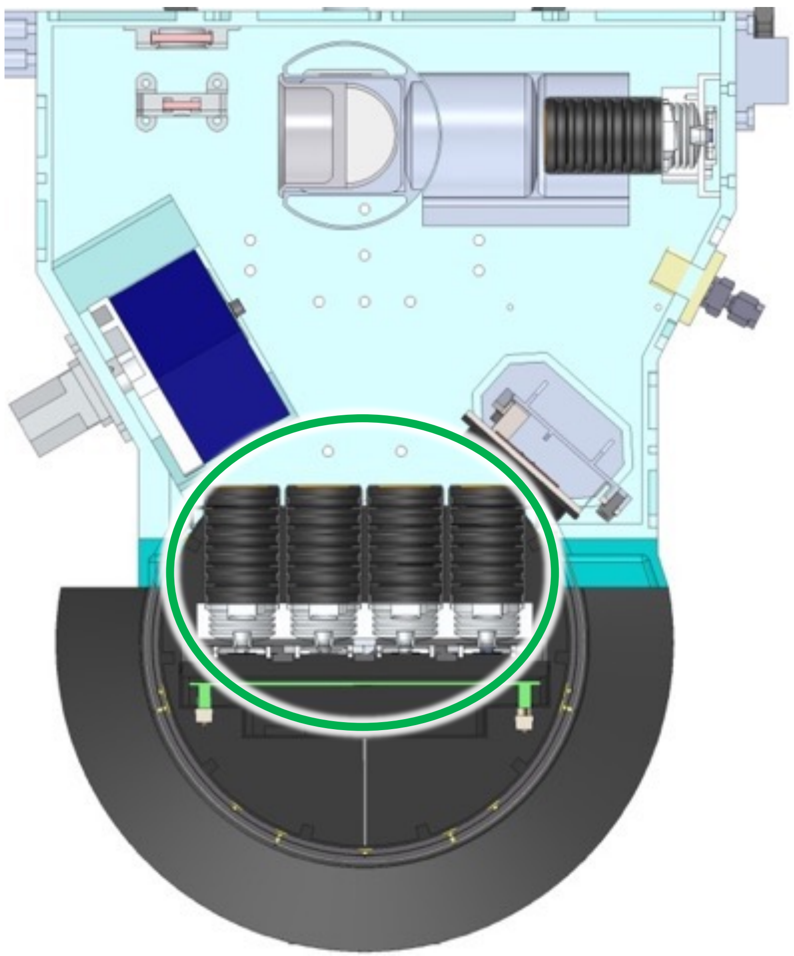


Radiometer and Calibrator Overview



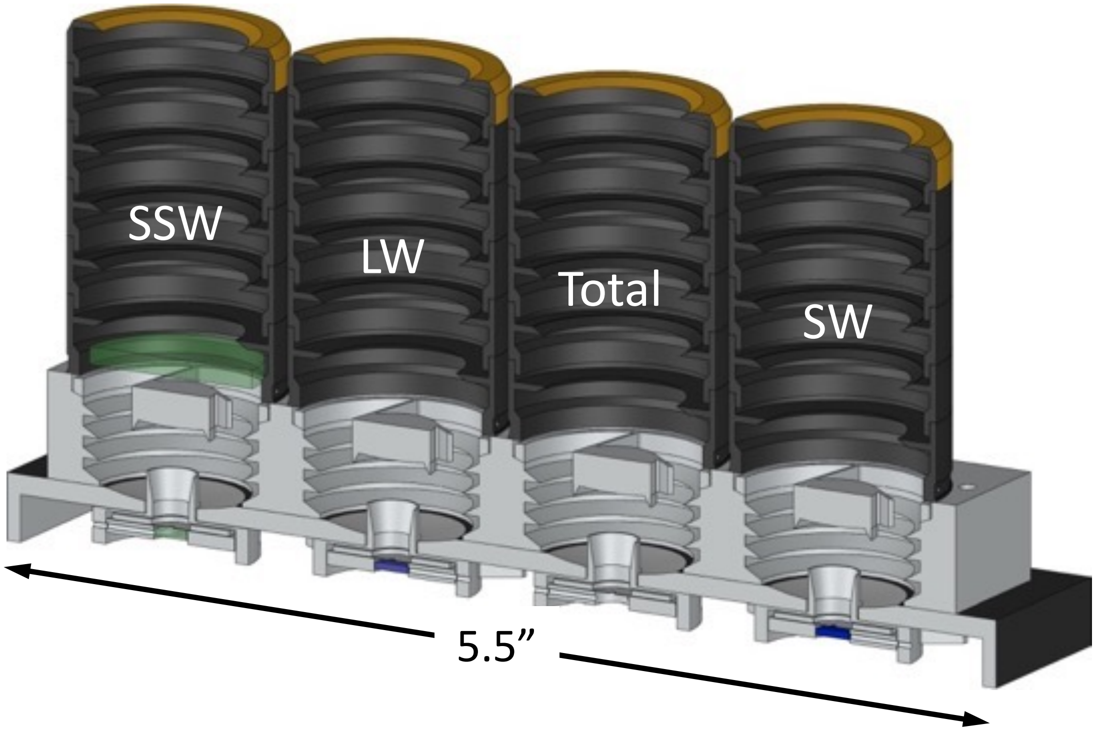
Radiometers





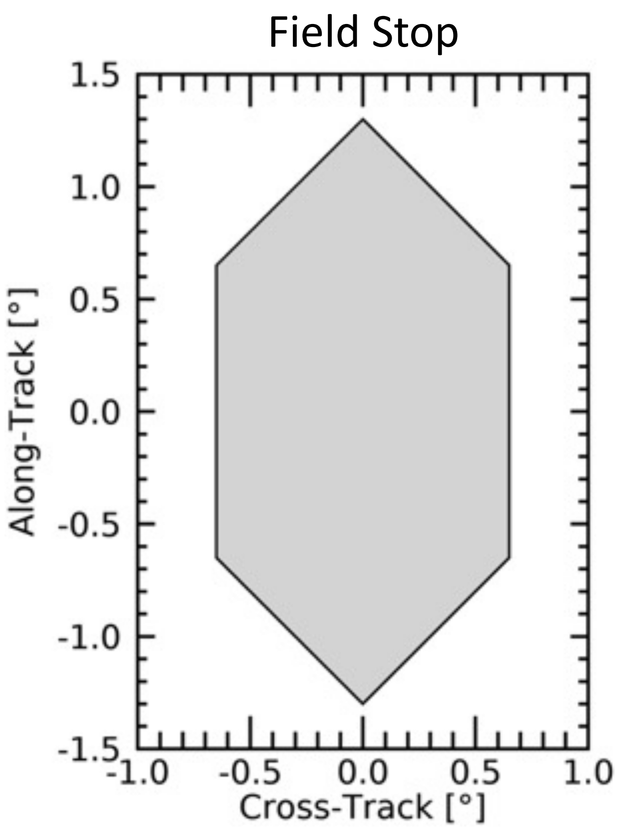
Telescope Implementation

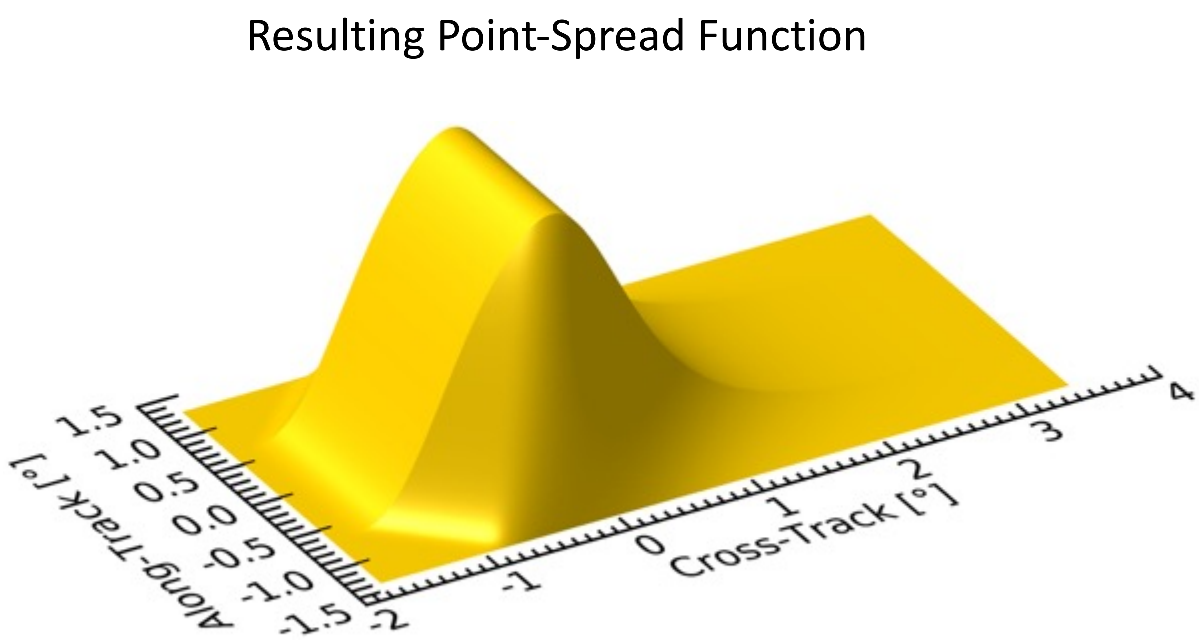
- The primary mirrors of all four telescopes are all diamond-turned from monolithic aluminum plate
- Telescopes are co-aligned prior to detector integration
- This design provides excellent thermal and alignment stability



Telescope Optical Design: Field Stop

- Libera field stop is same shape and angular size as CERES
  - Hexagonal 2.6˚x1.3˚
- Allows Libera to match CERES PSF





Detector

CERES

Open-loop bolometer

- Detector temperature changes
- Incident power is readout as a resistance change
- Time constant dependent on heat capacity and thermal impedance to the heat sink
- Black paint optical absorber

Libera

Closed-Loop Electrical Substitution Radiometer (ESR)

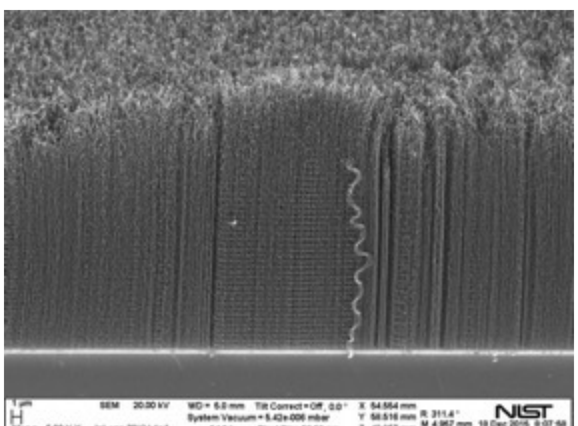
- Detector temperature is constant
  - Power dissipated in the detector is adjusted to maintain a constant temperature
- Incident power is readout as a change in electrical replacement power
- Time constant is dependent on internal detector thermalization
- Vertically-aligned carbon nanotube (VACNT) optical absorber

NIST Sources & Detectors Group

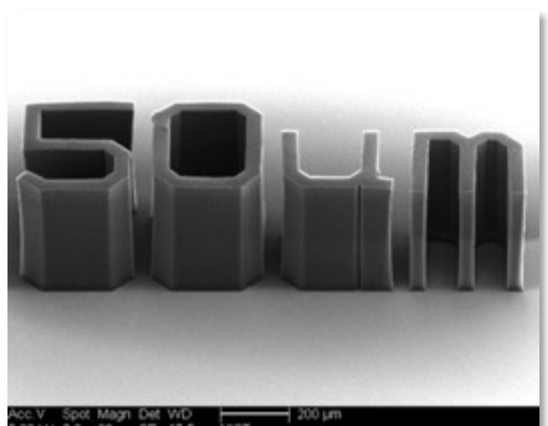
- NIST Boulder Sources & Detectors Group has lead the development of these detectors
  - LASP has been working with NIST on VACNT detectors since 2014
- ~1 month from silicon wafer to detectors
  - All fabrication occurs at NIST Boulder

Boulder Microfabrication Facility

VACNT SEM Image



Patterned VACNT

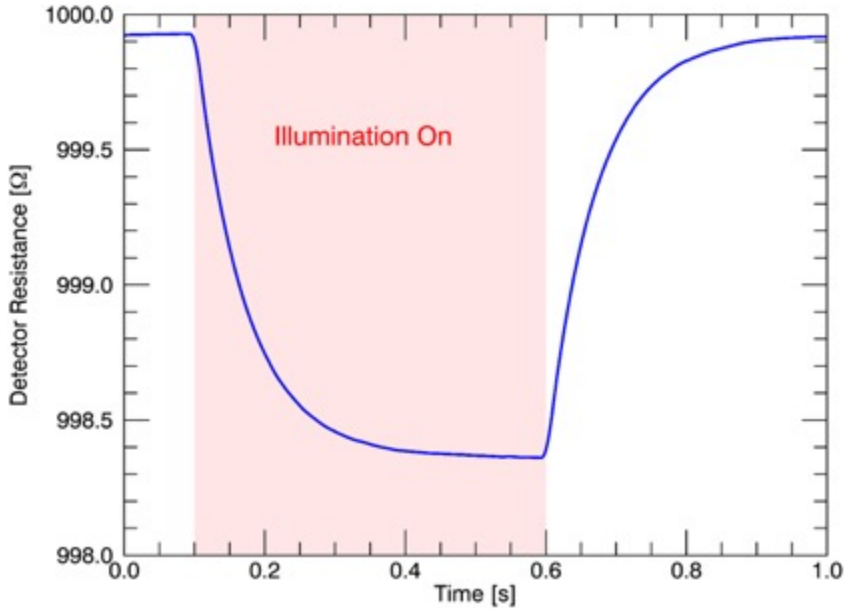


VACNT Growth System

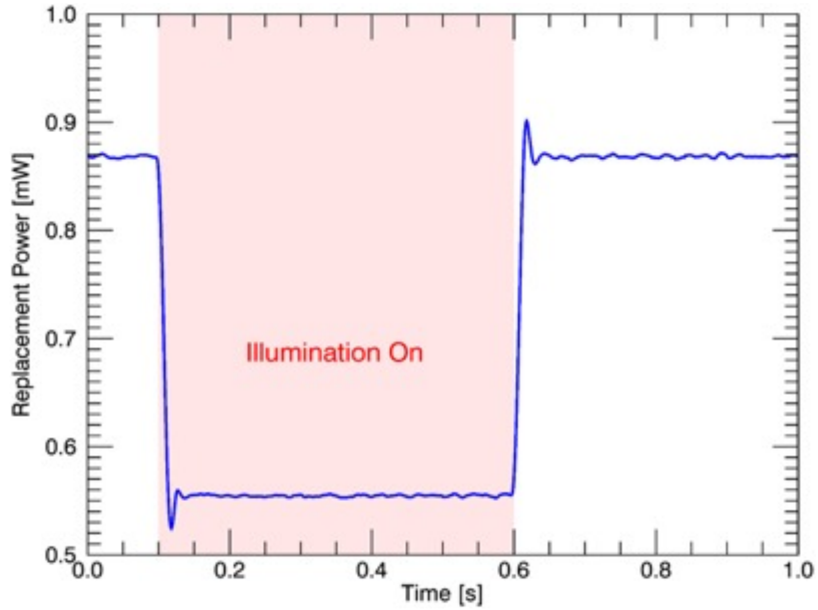
Open vs Closed Loop Comparison

- Demonstration of Open and Closed-Loop (ESR) operation
- This is actual measurement data taken with the same detector

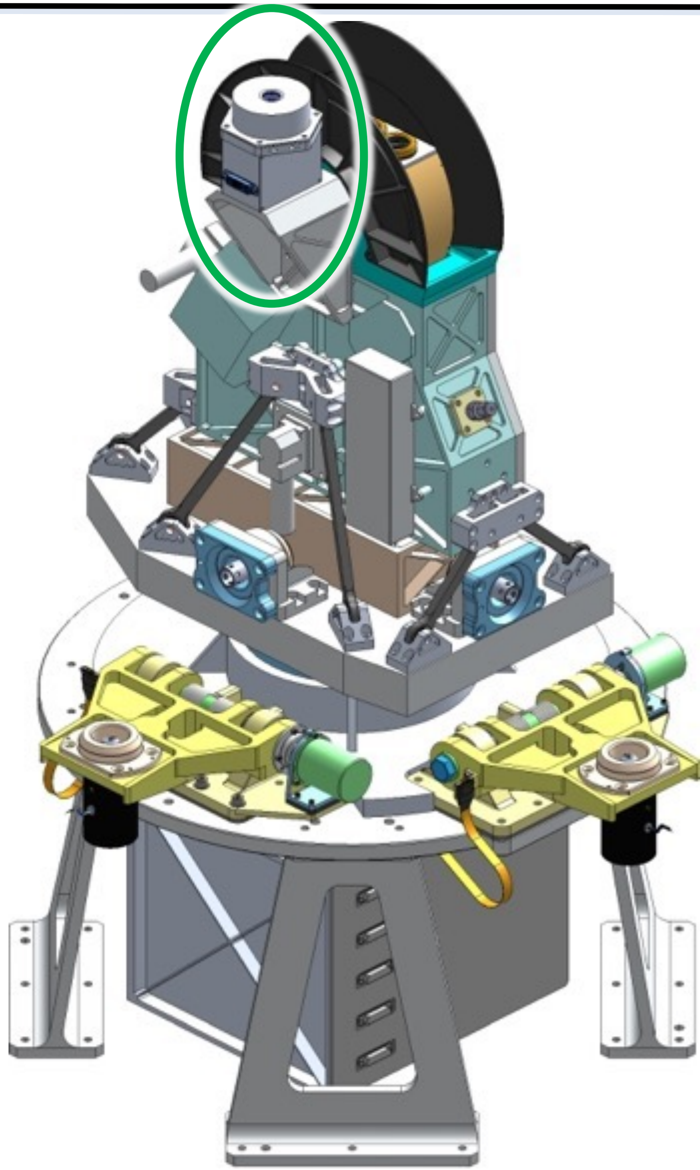
Open Loop



Closed Loop

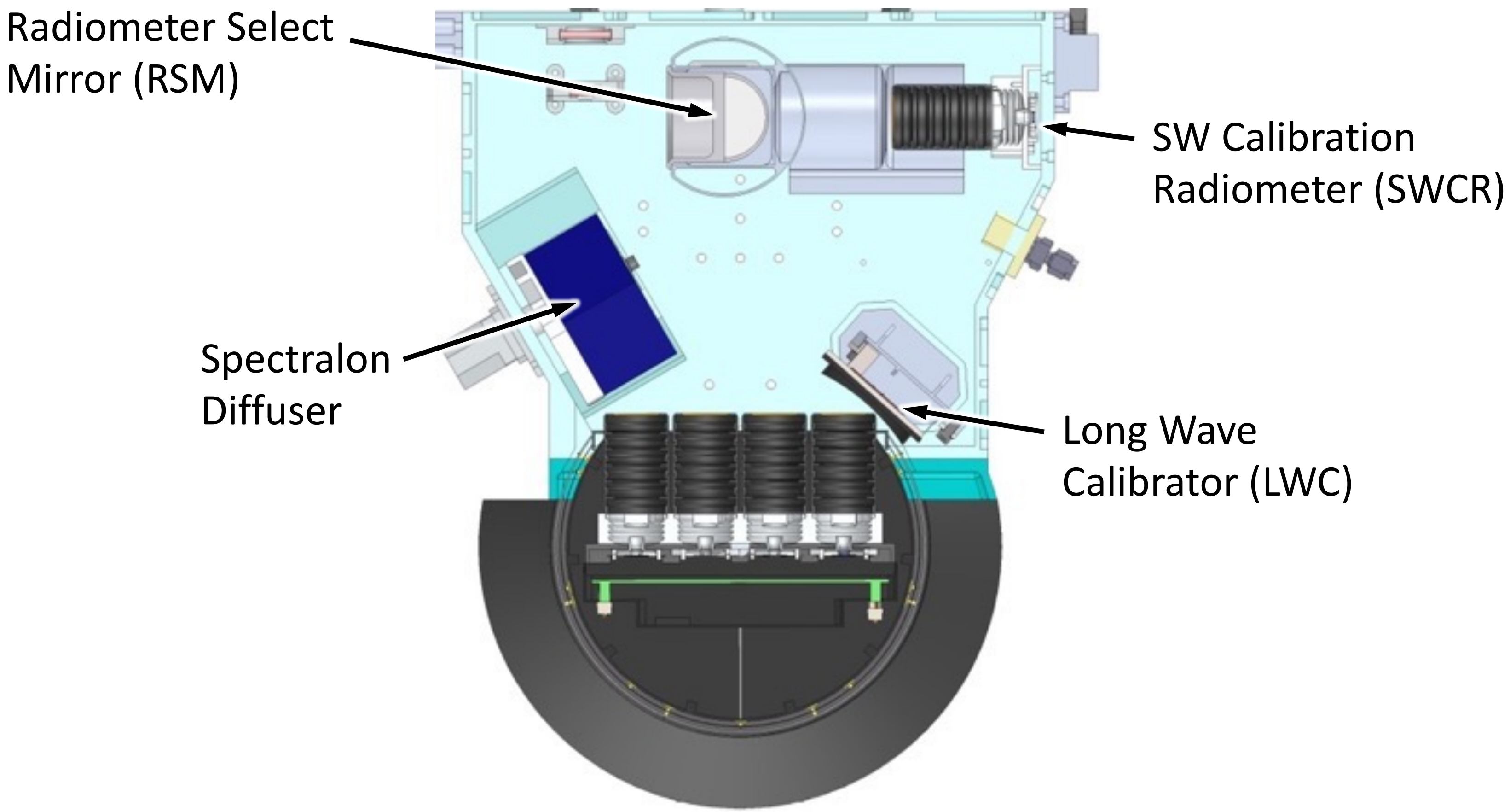


WFOV Camera



- 124˚ FOV
- 555 nm bandpass, 20 nm FWHM
  - Matches VIIRS M4 Band
- Allows multiple observations of the same location with different viewing zenith angles
- More details in next talk

On-Orbit Calibrations/Stability Monitors

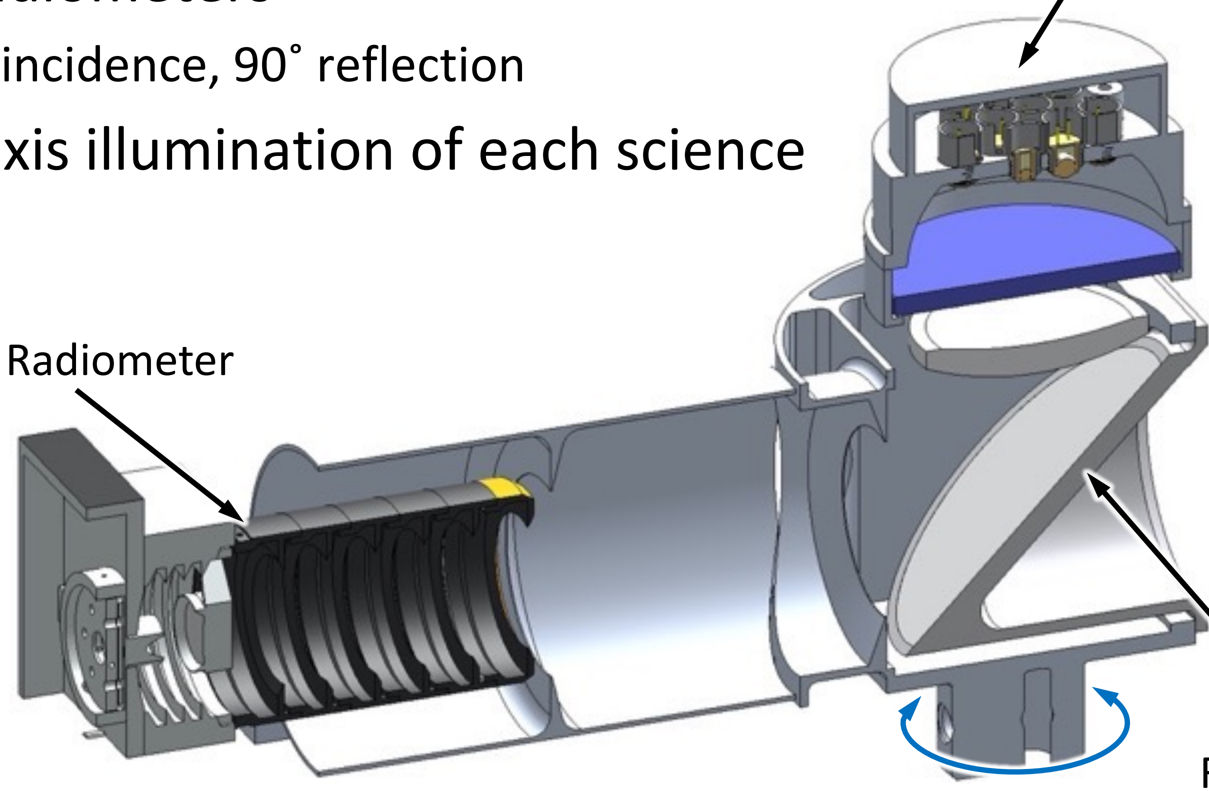


On-Orbit Calibrations/Stability Monitors

- SW Calibrator
  - Six discrete illumination wavelengths: 375, 405, 469, 660, 810, 1550 nm
  - Illumination is tracked with a replica of the total radiometer
    - Only views the SW Cal illumination, nothing external to the instrument
- LW Calibrator
  - Flat plate blackbody with VACNT high emissivity coating
- Solar Diffuser
  - Provides no spectral information, independent check for SW Calibrator
  - Three-surface Spectralon diffuser
    - Vary duty cycle use between faces to allow characterization of Spectralon degradation
- Lunar Views
  - Provides no spectral information, another independent check

SW Calibration System

- A folding mirror directs the illumination from the SW LED source to either the SW cal radiometer or the science radiometers
  - 45˚ angle of incidence, 90˚ reflection
- Provides on-axis illumination of each science radiometer

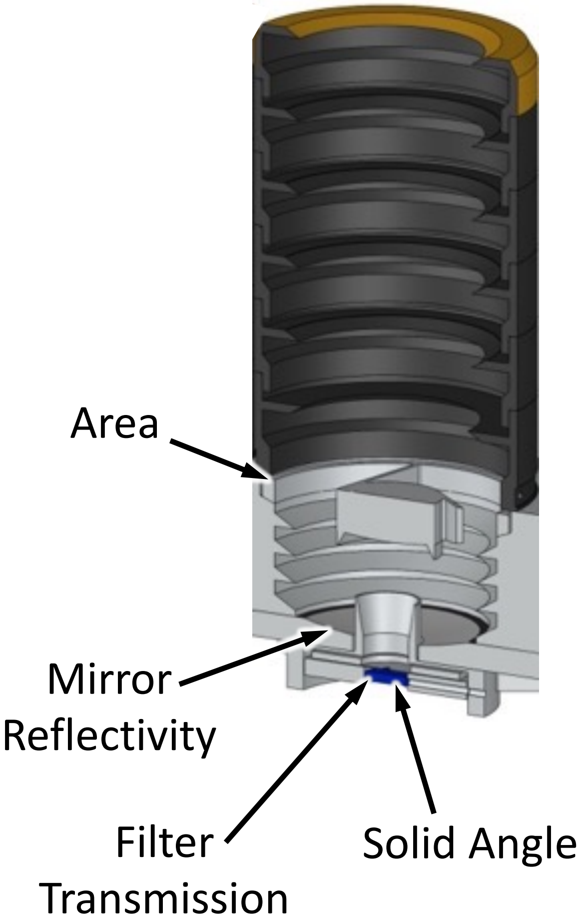


Libera Measurement Equation and Ground Calibration Plan

Libera Radiometer Measurement Equation

$$L = \frac{1}{R_M^2(\lambda) T_F(\lambda) \alpha(\lambda)} \frac{P(\lambda) - P_{DS}}{A\Omega}$$

Symbol	Term	Units
$R_M(\lambda)$	Telescope Mirror Reflectivity	-
$F_T(\lambda)$	Filter Transmission	-
$\alpha(\lambda)$	VACNT Optical Absorption	-
L	Radiance	W m^{-2} sr^{-1}
$P(\lambda)$	Measured Power	W
P_{DS}	Deep-Space Measured Power	W
A	Collection Area	m^2
Ω	Solid Angle	sr



Spectral Response Separation

$$L = \boxed{\frac{1}{R_M^2(\lambda)T_F(\lambda)\alpha(\lambda)}}\boxed{\frac{P(\lambda) - P_{DS}}{A\Omega}}$$

Spectral Response Function

- The spectral response functions are measured during the Libera calibration
- The unfiltering process uses these spectral response functions in the generation of higher-level data products

Filtered Radiance

- The level 1B Libera data product is this value

Radiometric Calibration Goals

$$L = \boxed{\frac{1}{R_M^2(\lambda)T_F(\lambda)\alpha(\lambda)}}\boxed{\frac{P(\lambda) - P_{DS}}{A\Omega}}$$

Spectral Response Function

Filtered Radiance

The goal of the Libera radiometer ground calibrations is to:

- Populate the measurement equation to allow accurate calculation of filtered radiance
- Measure spectral response functions to allow for unfiltering

Radiometer Calibration Overview

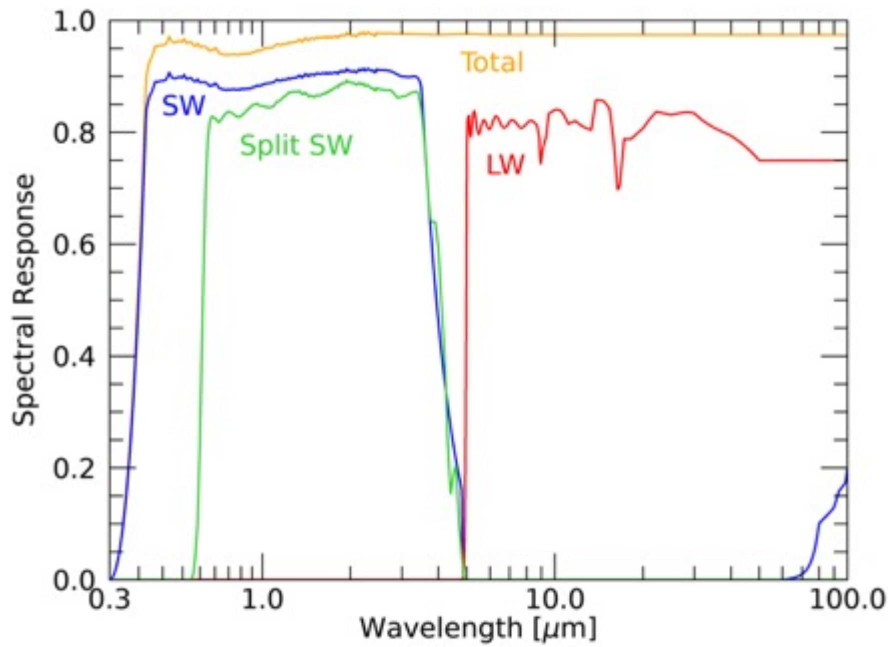
- Component-level
  - Component-level testing of flight components will:
    - Update values in the filtered radiance measurement equation
    - Spectral response functions generated from spectral measurements of components
- Detector-level
  - Electrical calibrations
    - Populate filtered radiance measurement equation
  - End-to-End testing of the detectors
    - Test time response, non-equivalence
- Radiometer-level
  - Validate and adjust filtered radiance measurement equation
  - Validate and adjust the spectral response functions
- Validation
  - *Independent check* performed at SDL to validate the filtered radiance measurement equation and spectral response functions

Current Design

Filtered Radiance Measurement Equation Values

Symbol	Term	Value	Units
A	Radiometer Area	$1.78\text{x}10^{-4}$	m^2
Ω	Solid Angle	$7.72\text{x}10^{-4}$	sr
V	Reference Voltage	TBD	V
R	Thermistor Resistance	TBD	Ω
R'_T	Top Resistor + MOSFET $R_{DS(on)}$	TBD	Ω
Z_H/Z_R	Electrical/Optical Equivalence Ratio	1	-

Spectral Response Functions



Telescope Component-Level Calibrations

Telescope Component-Level Calibrations

- Mirror figure
  - Check against the design
- Telescope imaging performance
  - Check against the design
  - Measurement of focal length
    - Input to the solid-angle
- Area
  - Measure clear aperture
- Field-stop
  - Measurement of dimensions
    - Input to the sold-angle

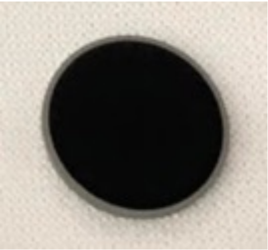
These measurements will be used to update filtered radiance measurement equation

Optical Witness Samples

Witness samples of mirror, filters, and VACNT coatings will be fabricated alongside the flight parts

- Mirrors
  - Flat 25-50mm diameter mirrors
  - Spectral reflectivity will be measured at NIST, LASP, and PTB

- Filters
  - Flat 25mm diameter filters
  - Spectral transmission will be measured at NIST, LASP, and PTB
- VACNTs (from detectors and LW blackbody)
  - Flat 25-50mm diameter samples
  - Spectral reflectivity will be measured at NIST, LASP, and PTB
  - Emissivity will be measured at PTB



These measurements will be used to update the spectral response functions

Physikalisch-Technische Bundesanstalt (PTB)

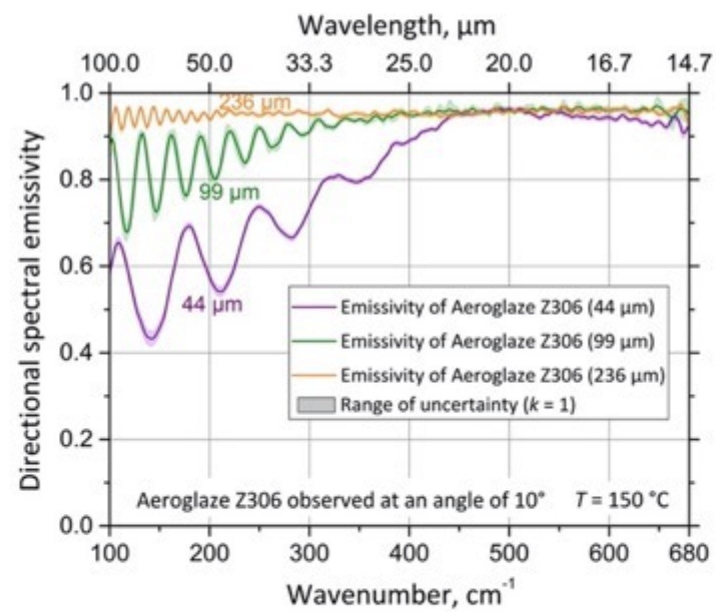
- PTB
  - German national metrology institute
  - They will provide spectral reflectivity and emissivity measurements beyond 25 μm
  - NIST currently tracible out to 25 μm
- What will be tested at PTB
  - Witness samples of
    - Mirrors
    - Filters
    - VACNT coatings
- PTB calibrations will improve the accuracy of the IR spectral response functions

Example PTB Spectral Emissivity Measurement:

Int J Thermophys (2017) 38:89
DOI 10.1007/s10765-017-2212-z
CrossMark
TEMPMEKO 2016

High-Accuracy Emissivity Data on the Coatings Nextel 811-21, Herberts 1534, Aeroglaze Z306 and Acktar Fractal Black

A. Adibekyan[1] · E. Kononogova[1] · C. Monte[1] · J. Hollandt[1]



End-to-End Calibrations

End-to-End Radiometer

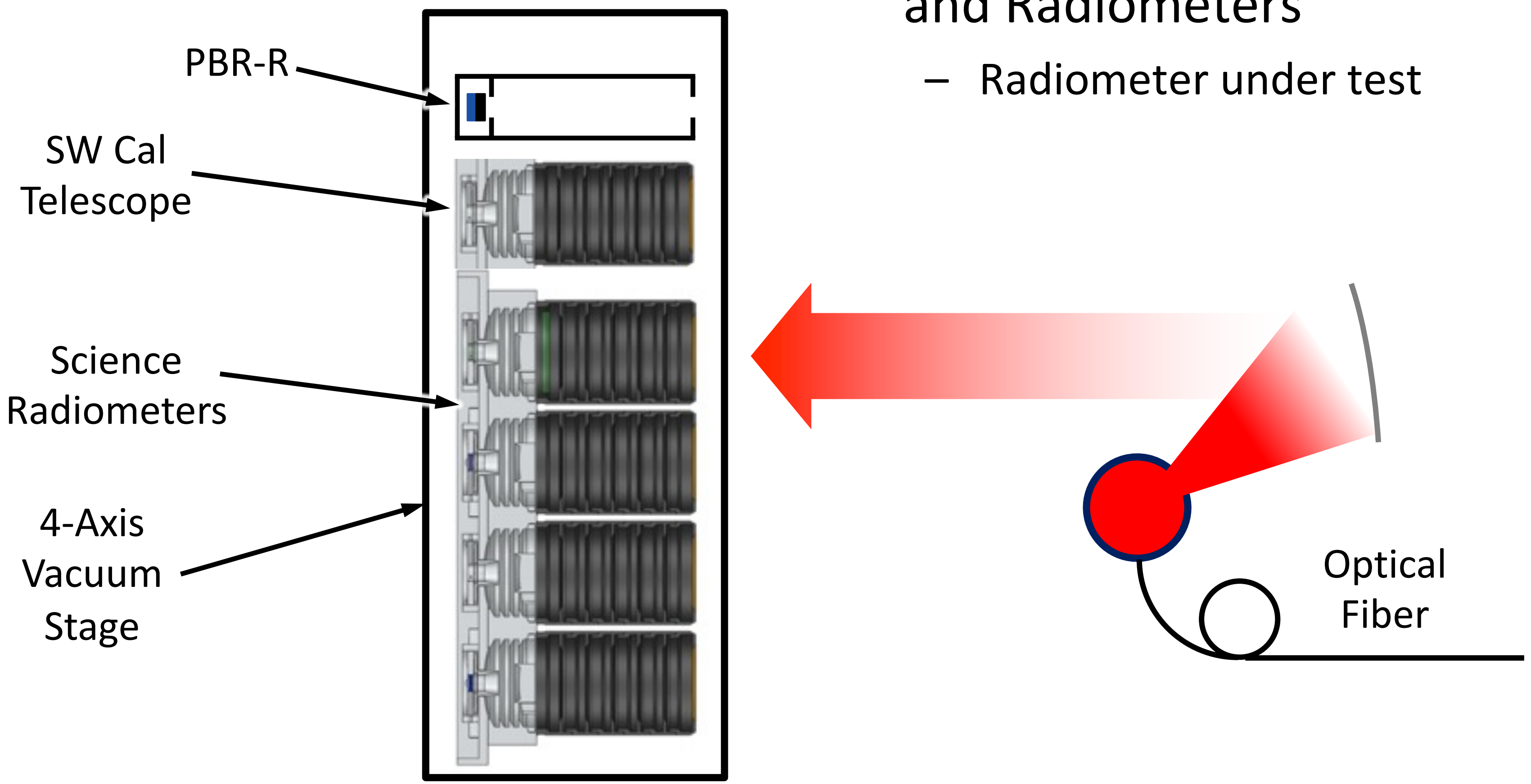
- The four science telescopes + SW Cal radiometer
  - Integrated with detectors
- Mounted on 4-axis stage in vacuum chamber

Measurements

- Radiance Detector-based
  - SI-Traceable radiance detector standard mounted next to radiometers
    - Planar Bolometric Radiometer for Radiance (PBR-R)
    - Pair of precision apertures spaced by known distance
    - VACNT ESR detector
  - Illuminate with collimated beam uniform radiance source
    - Collimated integrating sphere
    - Sphere fed with tunable laser
  - Calibrate radiance with PBR-R, check with radiometers
- Source-Based
  - Measure absolute IR radiance from precision ambient temperature blackbody

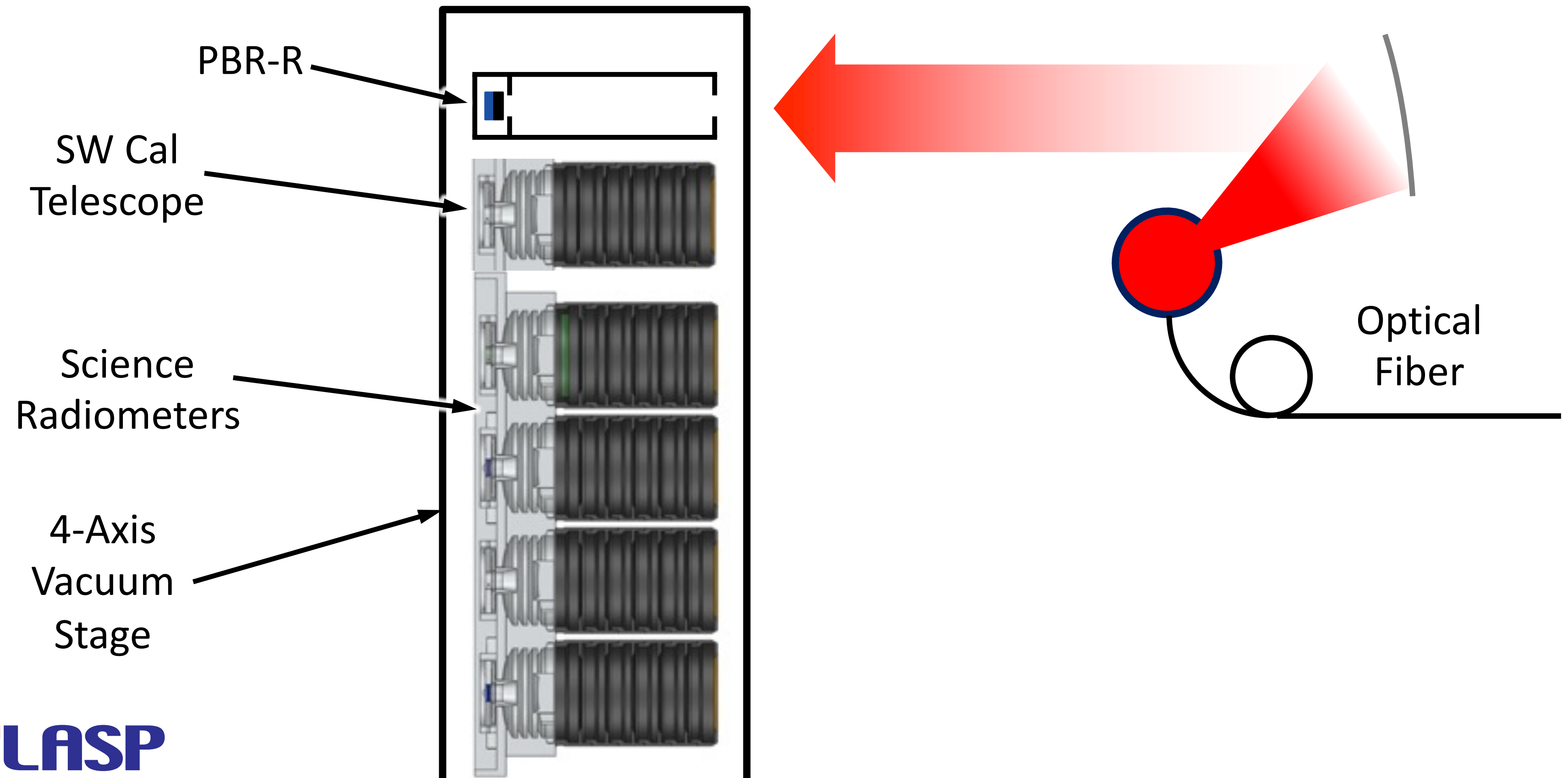
End-to-End Radiometer: Detector-Based

- Translated between PBR-R and Radiometers
  - Radiometer under test



End-to-End Radiometer: Detector-Based

- Translated between PBR-R and Radiometers
  - PBR-R under test



Planar Bolometric Radiometer for Radiance

- Planar Bolometric Radiometer for Irradiance (PBR-R)
- Pair of precision apertures
  - Separate by a precision distance
- Ambient-temperature VACNT ESR detector

Current estimated measurement uncertainty:

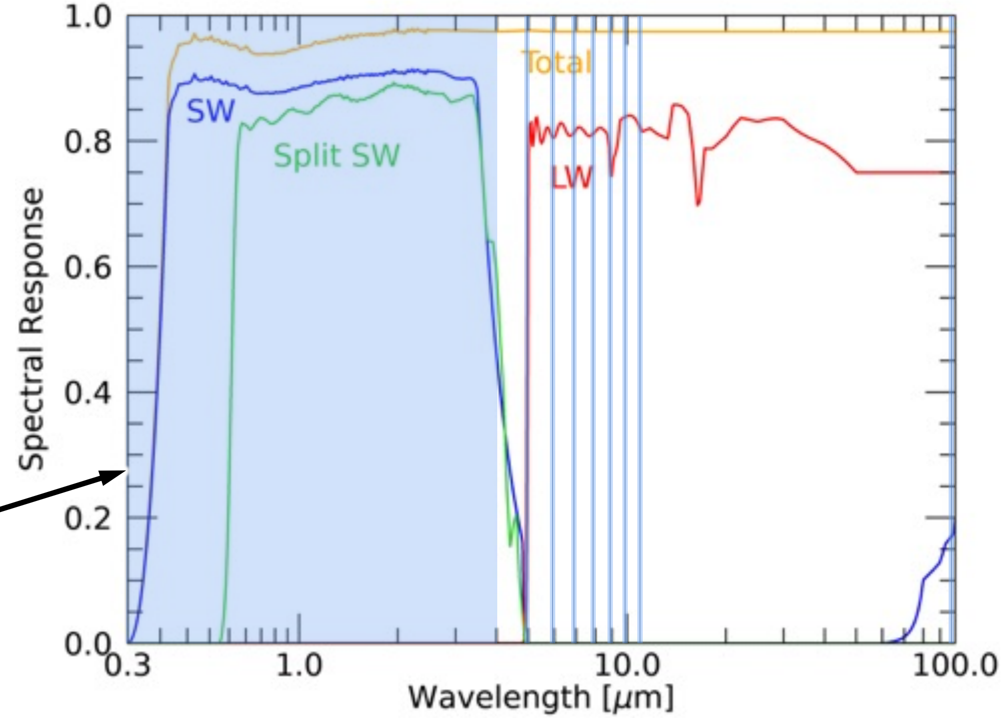
Term	532 nm k=1 [%]	10 microns k=1 [%]
Aperture Areas	0.01	0.01
Aperture Separation	0.02	0.02
Aperture Alignment	0.02	0.02
Optical Absorptance	0.005	0.100
Non-Equivalence	0.05	0.05
Electrical Power	0.005	0.005
Total	***0.06***	***0.12***

Detector-Based Uncertainty

- The uncertainty of the detector-based calibration derived from
  - Detector uncertainty
  - Stability and uniformity of illumination
  - Uncertainty in the inter-comparison
- Detector based calibrations will be used from 0.3-11 µm
  - Investigating sources beyond 11 µm
- At a specific wavelength we are also measuring the spectral response function at that wavelength

Term	532 nm k=1 [%]	10 microns k=1 [%]
PBR-R Uncertainty	0.06	0.12
Radiance stability	0.08	0.10
Radiance uniformity	0.10	0.10
Total	***0.14***	***0.18***

Detector-Based Calibration Wavelengths



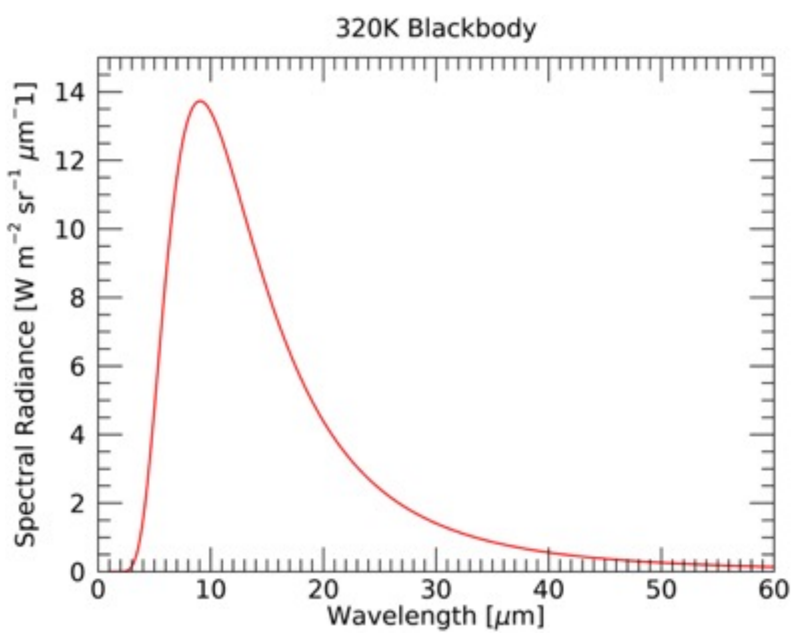
Blue indicates currently achievable laser wavelengths

- Continuous coverage to 4 μm
- QCL and CO_2 lasers to 5-11 μm
- Gas THz laser at 100 μm (lines at 97, 119, 184 μm)
- Investigating additional laser and narrow-band sources

Source-Based Uncertainty: LW, Total

- The uncertainty of the source-based calibration derived from:
  - 320K Blackbody, Radiance = 189 W m^{-2} sr^{-1}
    - Emissivity = 0.999 +/- 0.001
    - Temperature Uniformity & Accuracy 0.05˚C
  - 90K Blackbody, Radiance = 1.1 W m^{-2} sr^{-1}
    - Emissivity = 0.9 +/- 0.1
    - Temperature Uniformity & Accuracy 1˚C
  - Broadband measurement

Term	k=1 [%]
300K Blackbody Radiance	0.12
90K Blackbody Radiance	0.07
Radiometer Stability	0.1
Total	***0.17***

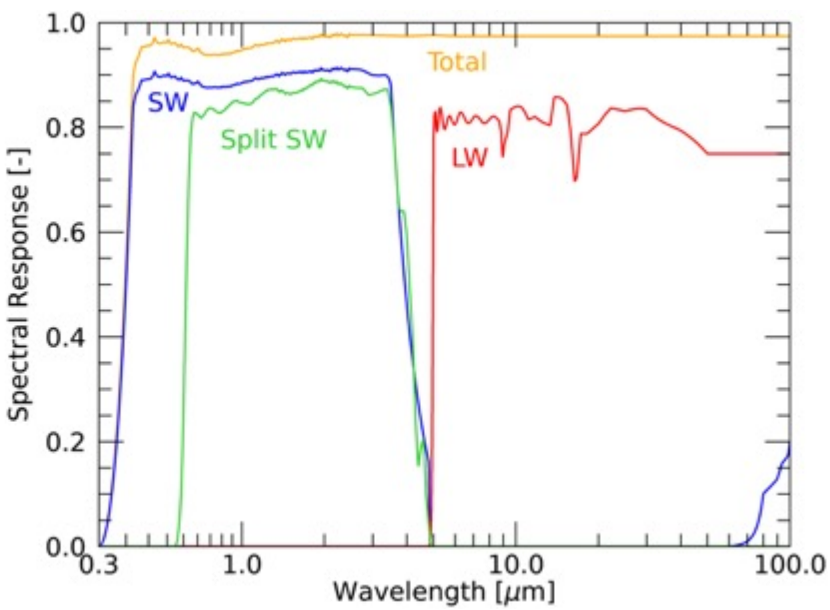


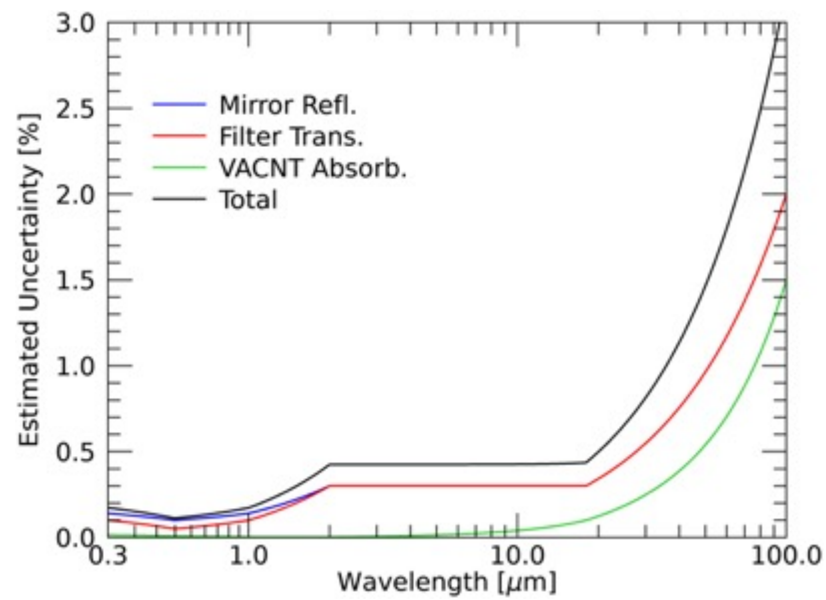
Spectral Response Functions

- Spectral Response Functions
  - A value and uncertainty as a function of wavelength for all channels

$$L = \frac{1}{R_M^2(\lambda)T_F(\lambda)\alpha(\lambda)} \frac{P(\lambda) - P_{DS}}{A\Omega} \qquad \frac{1}{R_M^2(\lambda)T_F(\lambda)\alpha(\lambda)}$$

  - Measured at the component-level
  - Validated during end-to-end



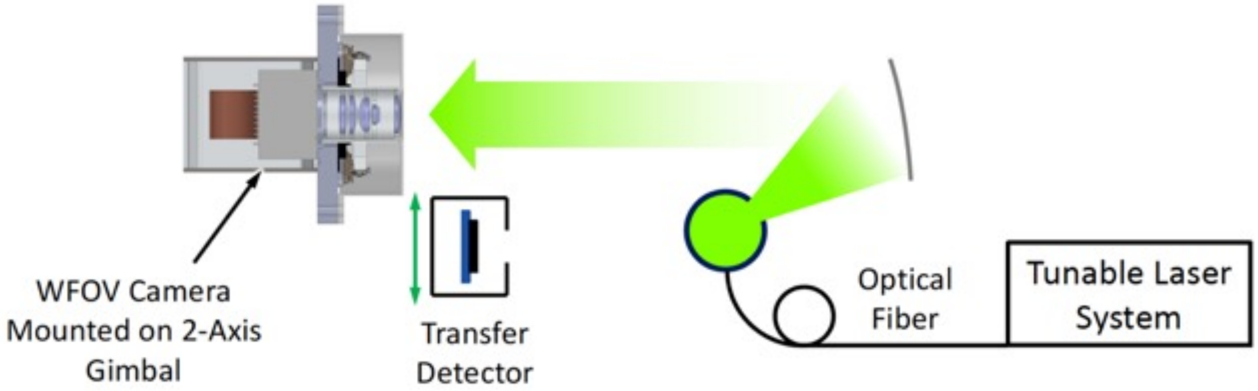


WFOV Camera Calibration

Libera WFOV Camera Ground Calibration

- Radiometric Calibration (<5%)
- Flat Field (<1.5%)
- Filter Spectral Response
- Image Distortion
- Detector Linearity
- Dark Current (Temperature)
- Stray light

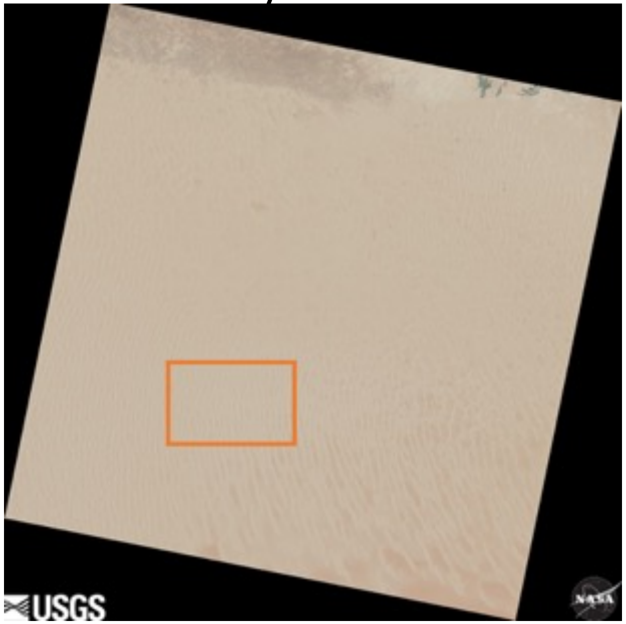
Flat Field & Radiometric Test Setup

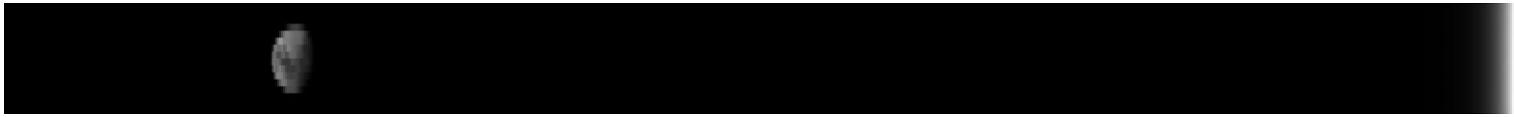


Libera WFOV Camera On-Orbit Calibration

- In camera LEDs
- Leverage VIIRS M4 for flat field (e.g. Sahara)
- Pseudo-Invariant Calibration Sites (PICS)
- Monthly Lunar Observations
- Monthly Upper Atmosphere Limb Observations

Libya-4





Lunar

Upper Atmosphere

Summary

- Libera has been designed to:
  - Maintain CERES continuity
  - Advance instrument accuracy and stability
- Instrument design being refined as we move towards PDR
- The instrument calibration concept has been defined
  - Currently refining the calibration plan and estimated uncertainties